Sensors & Controls

OBJECTIVE

Design and install a control system to dim lights and/or turn them off when there is adequate daylight.

- Reduce lighting energy consumption with automatic controls.
- Use a lighting specialist for best results with the control system.

KEY IDEAS

General

- **Sensors "measure" light** by looking at a wide area of the office floor and work surfaces from a point on the ceiling. The sensor's signal is then used by the control system to dim or turn off the electric lights according to the available daylight. These simple components are needed to save energy in daylighted spaces.
- **Controls can respond to many variables.** To save lighting energy, controls are typically designed to respond to daylight and a host of other inputs (e.g., occupancy sensors, weekend/holiday/nighttime schedules, etc.).
- **Include all control documentation in the construction documents.** This should include clearly developed control schematics, control sequences, calibration instructions, maintenance plans and checklists, and clear testing procedures.
- **Lighting controls and sensors must be properly calibrated and commissioned** prior to occupancy. This helps ensure energy savings and reduces the likelihood of complaints from occupants.
- **Take special care to document integrated control systems.** Control schematics are critical where different building systems (e.g., lighting, mechanical, etc.) come together. Identify responsibilities where integrated systems overlap, such as who adjusts each component, which warranties apply where, etc.

Type of Lighting Control

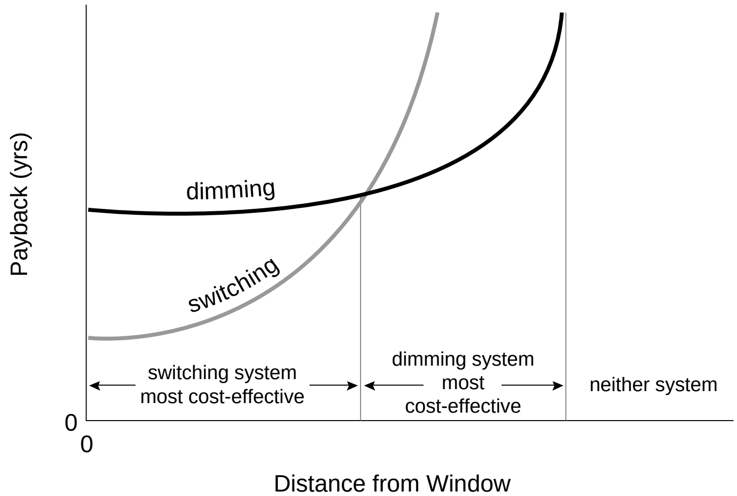
- **Choose either dimming or switching hardware** for a particular lighting zone. The choice of dimming or switching (on/off) equipment is partly dictated by the control strategies selected:

  Daylighting. Lights are dimmed in response to interior daylight levels.

  Scheduling. Lights are turned on, off, or dimmed according to day/night/holiday whole-building schedules.

  Lumen Maintenance. Captures savings by dimming new lamps until their light output has dropped down to the design level through aging and dirt depreciation. Lumen maintenance employs the same hardware used for daylight dimming and saves 10 to 15% annually.

  Tuning. Fine tune lighting levels after occupancy. Fine tuning is a control strategy where lighting is dimmed to meet local ambient or task lighting needs, and may save 10 to 15% of lighting energy.



Dimming/Switching payback chart

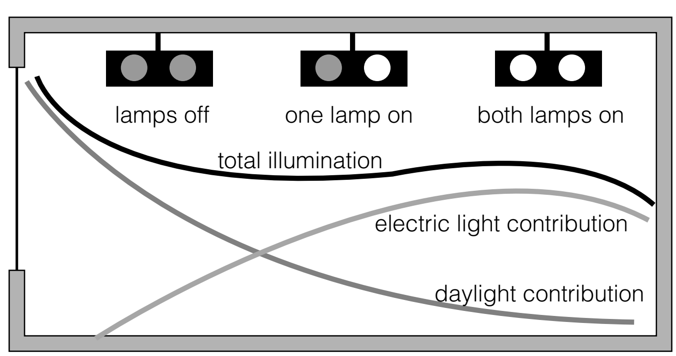
- **Choose dimming hardware if daylighting, lumen maintenance, or tuning are the selected control strategies.** With the cost of dimming ballasts still high but falling, dimming control is at least twice as expensive as switching control but it is the best for implementing these strategies. It is also generally the most acceptable to occupants, because changes in the electric light levels are least disturbing. Daylighting and lumen maintenance strategies integrate well, since they use the same hardware. Dimming is generally not cost-effective in non-daylit areas unless coupled with scheduling controls. Dimming can capture all possible daylighting savings. For spaces with adequate daylight all day long and for non-critical visual tasks, switching may be acceptable, since the lights may adjust only once or twice during stable daylight hours.
- **For all OTHER strategies, choose switching hardware.** Scheduling (either with automatic time controls or occupant sensors) can be implemented effectively with switching controls. Switching technologies are inexpensive, have a short payback period, and typically do not require special expertise to install. They are compatible with other lighting systems and are easily adjusted.
- **Select switching for daylight control with caution.** This hardware is less expensive than dimming, but has the disadvantage of abrupt light level changes. Switching is acceptable in intermittently occupied spaces or in spaces with fairly constant and adequate daylight all day (e.g., clear weather, large windows). In zones less than five feet deep from windows, simple on/off switching is the most cost-effective, especially if daylight is abundant. Do not use switching when it is anticipated that lights will turn on and off during occupied hours; case studies show occupants find this disruptive and will disable the system.
- **Do not count on manual controls.** Manual switching capability is already required by Title 24, but it is generally not well used by the typical office occupant. Use automatic controls to ensure that projected savings are actually achieved over time.
- **Use dual-level switching.** This wall-mounted switch reduces light levels by turning off individual lamps in 2-, 3-, or 4-lamp fixtures. This is the minimum switching requirement specified by California code. Dual-level or multi-level switching can also be activated by daylight sensors at less cost than dimming, but with better acceptance than simple on-off controls.

- **Use programmable time controls** for a more sophisticated form of scheduling control than simple timeclocks. This is good for facilities with many different daily schedules. Sweep-off control (after an initial warning, automatically sweeps off lights after the building closing hour) is effectively implemented with programmable controls and a manual override via wall switch or phone. This control strategy typically yields at least 15% savings in lighting energy and is helpful for picking up lights left on by after-hour workers or cleaning crews. If sweep-off control is used, wire lighting circuits back to the electric panel for operation by building controls.
- **Use occupancy sensors.** These are easily installed in wallboxes in lieu of manual switches. But only use wallbox occupant sensors if the sensor will have an unobstructed view of the space. If the sensor is obstructed, use a ceiling-mounted sensor instead. Occupancy control yields 15-30% savings and is highly cost-effective. Some units come with integrated photocells for both daylight and occupancy sensing.
- **Zones with daylighting should be separately switched from other zones**, even if daylight controls are not installed—this may be required by Title 24. This allows for future installation of daylighting controls if the project budget does not allow them in initial construction.

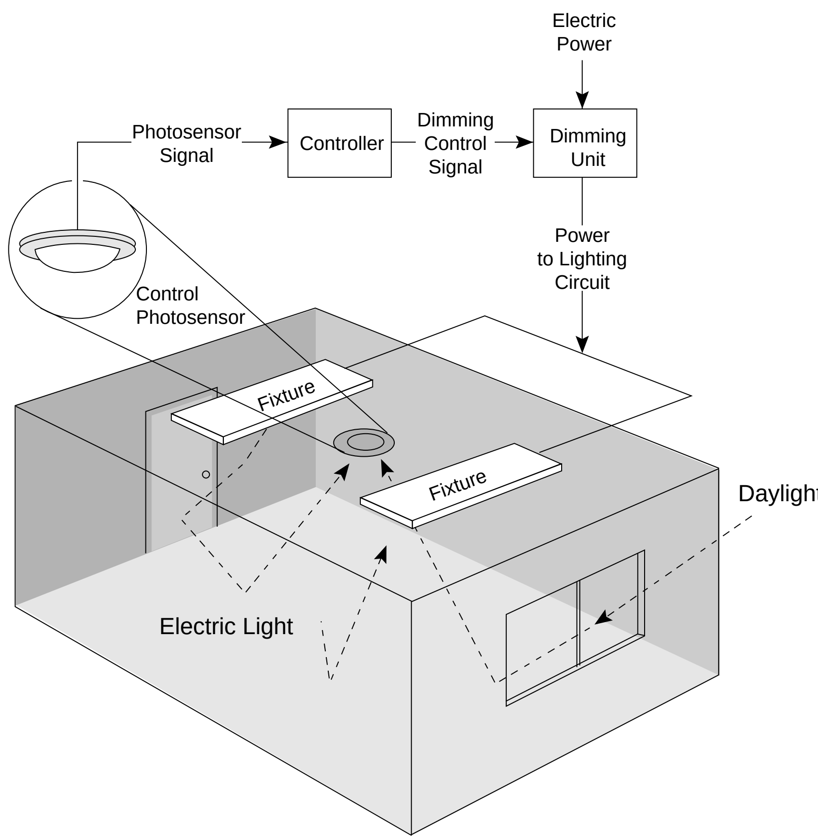
Zoning

- **Control zones should match areas of similar daylight availability and space function** (e.g., conference, computer, etc.). In open plan areas with a uniform window facade, group fixtures in runs parallel to the window with separate control for each row in from the window (for strip windows), or in groups associated with each window (punched windows).
- **Design control zones to correspond to window shading device zones.** For example, if an individual office contains manually operable drapes or blinds, the entire office would generally form (at least) one control zone.
- **Limit the number of zones where possible.** Costs go up with the number of control zones, so make zones as large as practical. However, too large a zone can lead to some areas being underlit.
- **Any circulation space running along a window-wall should be a separate control zone.** If this area is well-daylit, its lighting can often be switched off.

Schematic representation of lighting in a room with stepped lighting controls. The curves show relative light levels from both daylight and electric light. As the daylight level falls off with distance from the window, the electric lighting makes up the difference so that total illumination is evenly maintained at design levels thoughout the room.



Daylight Control Algorithm



Schematic diagram of a room with a photoelectric dimming system. The ceiling-mounted photosensor reads both electric light and daylight in the space, and adjusts the electric lighting as required to maintain the design level of total lighting.

- **Daylight control algorithms accommodate complexity.** They are the “smarts” that tell the electric lights what to do. Since the intensity and spatial distribution of daylight changes over time, these smarts have been designed to provide sufficient light under these complex conditions.
- **Open- and closed-loop are the two basic algorithms for daylight controls.** “Open-loop” and “closed-loop” are common control terms that indicate whether (closed) or not (open) information is fed back to the system to achieve control objectives. Open-loop systems cannot compensate for electric light losses (lumen maintenance strategy), but afford greater flexibility in calibration than most closed-loop systems. They are also more “forgiving” to errors in sensor placement or field of view. Some closed-loop systems that work with daylight may cause electric light levels to drop below design light level under some conditions, especially if the photocell is located too close to the window or is able to "see" out the window.
- **For switching systems, it is recommended that both the time delay and setpoint deadband be independently adjustable.** With variable cloudy conditions, the deadband adjustment alone may be insufficient to prevent system oscillation between the ON and OFF state (“hunting”).
- **For switching systems, control trigger points should be carefully set to avoid occupant dissatisfaction.** The light level at which the device switches off should be at least twice the level at which it switches on (i.e., twice the light level produced by the luminaire) to ensure that the design illuminance is met at all times.
- **System should be slow in response to sudden daylight changes.** The dimming response time (the time it takes for the system to respond to a sudden change in light level) is typically set around 30 seconds, to avoid unnecessary response to temporary conditions like moving clouds.

Sensor Location

- **Place sensor appropriate to the task location.** In a room with only one task area, place the ceiling-mounted sensor above the task. In a room with more than one task area, place the ceiling-mounted sensor above the task that best represents the daylight available. Some controllers support inputs from more than one photosensor. This allows daylight to be sampled at more than one location.
- **Sensor placement is determined by the daylight control algorithm.** For closed-loop control systems, locate the sensor at a distance from the window equivalent to approximately two-thirds the depth of the daylight control zone. Photosensor location is less critical with open-loop systems, and can be compensated for during commissioning. With a light shelf and an open-loop control system, locate sensor above the shelf.
- **Sensor placement differs with the type of lighting system.** With indirect and direct/indirect lighting systems, the photosensor should be located in the plane of the fixtures aimed downwards. Make sure that the sensors cannot directly "view" the electric lights they control. For direct lighting systems, recess the photosensor(s) in the ceiling.
- **Sensor field of view is important.** The photosensor's field of view should not be too narrow and restricted or the sensor will be too sensitive to small incidental changes (papers moving on desk, people nearby, etc.). A ceiling-mounted closed loop sensor should have a large field of view and be shielded from direct light from the window. Some sensors come with sun shields for cases where the cell can not be placed far enough from the window. For switching systems, the photosensor (often a photorelay) is located so that it "views" the external daylight source with minimal (or no) view of the electric lights that it controls.

Hardware

- **Choose dimming electronic ballasts,** now available from several vendors. All dimming ballasts operate fluorescent lamps in rapid-start mode, i.e., the fluorescent lamp cathodes are supplied with power at all times during operation.

- **Choose a system with sufficient control flexibility.** Switching systems should allow independent control of the ON setpoint light level (the light level on the photorelay that causes the lights to switch ON) and the OFF setpoint.

- **Combine occupant sensors with photocells.** Many occupant sensors (especially wallbox units) include daylight photosensors, although this may not be an optimum location for sensing task daylight. If the photosensor determines that the daylight level is adequate, the occupant sensor will not turn on the lights automatically when the occupant enters. The occupant may manually switch on the lights if desired.

- **Choose manual-on, automatic-off occupant sensors.** Several manufacturers now offer these sensors on the principle that occupants need help only in turning lights off, not on. The occupant must turn the lights on, and the sensor turns them off when occupant is absent. Some come with integrated daylight sensors.
- **Ensure compatibility of hardware components and controls**; especially when using controls from several different manufacturers (ballasts, ballast controllers, sensors, lamps, etc.).

Occupant Satisfaction

- **In general, dimming hardware is preferred by occupants** because the changes are less noticeable. If lighting changes are too abrupt, case study experience shows occupants tend to be disturbed or otherwise unsatisfied with the system. If the lighting controls are not expected to operate more than once or twice during occupancy (for example, if daylight levels are adequate all day such that the system perhaps operates only morning and evening), then switching hardware may be equally acceptable.
- **Switching hardware will be more acceptable if coupled with split-wired lighting.** Split-wiring, also known as stepped switching, allows lights to be switched in discrete steps (OFF, 1/2, FULL or OFF, 1/3, 2/3, FULL), so the changes are not so abrupt.
- **Avoid daylight controls on downlights.** Switching hardware with daylighting control is generally not acceptable for downlight fixtures, especially if fixtures are turned on and off (rather than split-wired), because occupants find automatic switching of electric lighting to be disruptively noticeable.
- **Occupants will disable a system they find unsatisfactory.** There may be any number of causes for negative user reaction to automatic controls. Choose an approach to controls that will most likely meet user needs, and ensure that the system will be installed and calibrated so that it operates properly. An unpredictable or poorly functioning system is a major cause of occupant dissatisfaction. Another problem may be the occupants' sense that the system is beyond their control. In these cases, visible manual controls are important, and manual overrides, while they may result in lower savings, will increase user satisfaction. Another problem witnessed in case studies is that an office with lights on signals that its occupant is in the building. Dimming strategies may be useful here. These issues should be discussed with the building owner during design and followed up with occupant education during the commissioning and occupancy phases.

INTEGRATION ISSUES

ARCHITECTURE

Window location, task location, and shading strategy affect control zoning.

INTERIOR

Space planning, finishes, and furnishings are strongly tied to control zoning.

HVAC

Perform load calculations accurately, with lights dimmed at peak cooling conditions. The lighting designer should supply expected lighting power reductions to the HVAC designer, or use advanced energy analysis software that can model daylight controls.

LIGHTING

Control system and hardware must be compatible with other lighting equipment.

COST-EFFECTIVENESS

Most building controls designed for energy efficiency are highly cost-effective, especially when supported by utility incentives. Simple lighting controls such as occupancy sensors are especially cost-effective.

OCCUPANT COMFORT

Tolerance for fluctuation in electric lighting levels varies. We experience lighting fluctuation all the time in the natural environment but tend to find changes in the artificial environment disturbing.

Some people are uncomfortable with a highly automated environment. Others may want lights on for non-task reasons (e.g., employee is "in" the office). These and other reasons can cause occupants to disable the system. Discuss these issues with building owner, building manager, and occupants.

! PROVISOS

- Never turn off lights automatically at night in an occupied space without a prior warning, such as flashing the lights ten minutes before shut off. This gives occupants a chance to manually override the shut off.
- Calibration of automatic daylighting systems and occupant sensors should always be performed after furniture installation is complete (see CALIBRATION & COMMISSIONING).
- Daylight levels are hard to predict, however it's important to have a good estimate of expected daylight in order to choose between dimming and the less expensive switching hardware. Photometry in a scale model is recommended, although a hand or computer-based calculation is acceptable.
- Savings from daylighting controls depend on their regular and maximum use. This in turn depends on adequate daylight entering the space. Be sure window glare has been properly addressed during design so that occupants will not always be deploying opaque window coverings to control glare.

- Be sure automated lighting controls will be acceptable to the building occupants on principle. Dissatisfied occupants frequently disable lighting control systems for a variety of reasons, only some of which are related to comfort or visual performance.
- Occupants may inadvertently disable controls by rearranging furniture, placing portable heaters near occupancy sensors, etc. Avoid this by educating occupants as to the function and operation of the control system.
- Note this section does not treat mechanical HVAC controls, as these are not generally linked directly with daylight controls. However, other lighting controls can be integrated with mechanical controls (occupancy sensors are a good example).

T TOOLS & RESOURCES

- **Design Professionals** The use of a lighting designer with experience in daylighting controls is highly recommended.
- **Manufacturers** This is the primary source of assistance available for control system products. The more complex the system, the more critical it is to work closely with the manufacturer through design, calibration and commissioning.
- **IES** The Illuminating Engineering Society is a resource for literature, standards, codes, guidelines, and a monthly journal covering lighting, daylighting, and visual comfort. These materials address a large range of useful and up-to-date technical information. Local chapters also may offer classes or other resources. For publications, call (212) 248-5000, ext. 112.
- **EPRI** The Electric Power Research Institute has a strong collection of fact sheets, brochures, guidelines, and software available. Call EPRI Lighting Information Office (800) 525-8555.
- **California Energy Commission** The CEC administers California Energy Code (Title 24) and offers good literature and design guidelines to assist with compliance, along with code documents. Contact the CEC at (916) 654-4287 to request a publications list. Many lighting controls are already required by Title 24.
- **International Association for Energy-Efficient Lighting** The IAEEL issues a useful quarterly newsletter free of charge. Write to IAEEL, c/o NUTEK, S-11786, Stockholm, Sweden and request placement on the newsletter mailing list.
- **LBNL Lighting Systems Research Group** is a good source of information on all aspects of energy-efficient lighting practices. For a publications list, contact Pat Ross at (510) 486-6845, or visit the Group's website at http://eande.lbl.gov/BTP.
- **Lighting Research Center**, at Rensselaer Polytechnic Institute, is source of general information about lighting products and practice. Contact them at (518) 276-8716 or http://www.lrc.rpi.edu.
- **Calculation Methods** Accurate estimation of energy and peak demand savings due to daylighting controls is complicated and is best accomplished with advanced energy simulation software that can model daylighting. The best source for reference material on this topic is the IES (see above (i.e., the IESNA magazine *Lighting Design + Application*, Software Survey, September 1996)). Many lighting designers

use daylighting software such as Lumen Micro and LightScope (available from Lighting Technologies, Inc., 303-449-1822), Luxicon (available from Cooper Lighting, 708-806-3553), LightCAD and BEEM (available from EPRI, 612-938-6014), and Adeline and Radiance (available from LBNL, 510-486-4757) in place of tedious hand calculations. For a list of lighting design software with daylight capabilities, request a "Daylighting Design Tool Survey" from the Windows and Daylighting Group at the Lawrence Berkeley Laboratory (510) 486-5605.

- **ASHRAE** The American Society of Heating, Refrigerating, and Air Conditioning Engineers offers a wide range of technical support materials for mechanical systems, including the monthly *ASHRAE Journal.* Up-to-date controls information may be found in this literature. Call 800-527-4723 for a publications list. For *ASHRAE Journal* subscription information, call above number or 404-636-8400.
- **Utility Company** Some utilities offer workshops, design assistance, publications, and sometimes incentives for controls in both new and retrofit projects. Inquire at your local utility about these programs.
- **Books** Controls are changing so rapidly, especially in DDC (direct digital controls) and HVAC applications, that books on the topic are often quickly out of date. The most current information comes from manufacturers, the IES, and ASHRAE. Check the *Consulting-Specifying Engineer Magazine* (708-390-2387) or the ASHRAE Journal.

  Control Systems for Heating, Ventilating and Air Conditioning, 5th Ed., by R. Haines and D. Little (Van Nostrand Reinhold 1993).

Advanced Lighting Guidelines: 1993, from the U.S. Department of Energy, is a thorough and informative guide to all aspects of various lighting technologies.

✓ CHECKLIST

1. Discuss controls, occupant behavior, and occupant expectations with building owner.
2. Select either switching or dimming hardware for each zone, depending on control strategy.
3. Meet or exceed all Title 24 lighting control requirements.
4. Don't rely on manual controls for savings.
5. Programmable time controls, occupancy sensors, and lumen maintenance are all good strategies for energy efficiency on top of daylighting.
6. If daylight controls get cut from the budget at this point, switch daylighted zones separately anyway, to allow for daylighting controls in the future.
7. Lay out control zones to match daylight availability and space usage.
8. Choose the most appropriate daylight control algorithm.
9. Specify proper sensor locations, depending on lighting system, task locations, control algorithm, and sensor field of view.
10. Choose the right hardware.
11. Take extra time to coordinate any integration between control systems, such as an occupancy sensor that triggers both lights and a VAV damper.
12. Include full documentation of controls, along with calibration and maintenance plans, in the construction documents.
13. Address occupant satisfaction and education during the commissioning and occupancy phases.

If you have...

no time

1. Dispense with daylighting controls at this stage if you have not previously used them in a project. Perhaps they can be installed in the future.
2. Design the lighting system to accommodate the addition of daylighting controls in the future.
3. Follow Title 24 control requirements.

a little time

1. Include a lighting designer on the project team.
2. Use dimming daylight controls as much as possible in perimeter zones.
3. If budget is restricted and daylight is abundant, use stepped switching instead of dimming hardware in perimeter zones.
4. Use simple on-off switching elsewhere.
5. Use occupancy sensors wherever appropriate.
6. Use time clock controls for after-hours savings.
7. Follow or exceed Title 24 control requirements.
8. Take care to anticipate occupant dissatisfaction with controls.
9. Make the control documents, including calibration and maintenance plans, part of the construction documents.

more time

1. Include a lighting designer on the project team.
2. Perform computer analysis to accurately estimate control savings and use results in a cost/benefit analysis to help determine best combination and types of control strategies.
3. Use dimming daylight controls as much as possible in perimeter zones.
4. Use daylighting controls in a lumen maintenance strategy as well.
5. Use occupancy sensors wherever appropriate. Combine with the photocell in perimeter zones.
6. Use programmable time clocks and sweep-off control for after-hours savings.
7. Follow or exceed Title 24 control requirements.
8. Work with building owner to resolve any anticipated trouble with occupant acceptance of the control system.
9. Explore opportunities to integrate with mechanical controls and tie into energy management control system, if any.
10. Make the control documents, including calibration and maintenance plans, part of the construction documents.
11. Verify that occupants are satisfied with the controls after calibration and occupancy. Educate occupants and building manager about the function and purpose of the sensors and the control system.